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Intermodal Terminal Design for Autonomous Freight Transportation Systems

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ABSTRACT

This paper investigates the design and operation of an intermodal terminal for Underground Freight Transportation (UFT) system. UFT is considered as a new mode of freight transportation that uses pipelines for transporting freight between two intermodal terminals. The load size and route length of the UFT system can be variable depending on the purpose and specifications of the project. In this paper two sizes of loads and two route lengths are considered to show that the terminal design and operation are independent from route length and load size. Each UFT route starts at the Port of Houston where shipping container or pallet size loads will be delivered to the UFT system. The short-haul route ends at a proposed intermodal satellite terminal outside Houston and the long-haul route terminates in a proposed intermodal inland port in Dallas. This paper develops inclusive equations to estimate the operational attributes of the UFT intermodal terminal. These attributes include operational headway, system flow, fleet size, and number of handlers/forklifts required in operation of the terminal. Based on the terminal operation requirements, a typical design for a UFT intermodal terminal is presented. In addition, the loading/unloading process and the freight circulation scheme are discussed. Although, this schematic terminal design and operation are for shipping container loads, but the same concept can be applied to smaller scale loads such as pallets.

Keywords: Freight Transportation, Intermodal Terminal Design, Freight Pipeline, Intermodal Transportation System, Underground Freight Transportation

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INTRODUCTION

The freight pipeline transportation system is neither a conventional rail system nor a replacement for the truck transportation system. Freight pipeline transportation is a new intermodal system for freight transportation which is designed to complement the latter systems in meeting the anticipated future growth in freight transportation. The Texas transportation system is critical to the US due to the North American Free Trade Agreement (NAFTA) between the US, Mexico, and Canada with freight transportation in the Port of Houston serving as a first ranked US port in foreign tonnage. Through 2030, NAFTA trade will increase by nearly 207 percent by tonnage (Najafi, 2017). This will have a profound impact on the Texas highway and rail systems. Therefore, increasing the capacity of the freight transportation system is a must.

GOAL AND CONTRIBUTION

The goal of this research is to represent schematic designs for Underground Freight transportation (UFT) intermodal terminals and elaborate loading/unloading process. The research tries to calculate operational attributes prevailing in UFT terminals and scrutinizes the freight circulation in the terminal area. The freight pipeline is a class of unmanned transportation systems in which close-fitting capsules or flat-bed gondolas carry freight through pipelines or tunnels between terminals. The objective is to present a schematic planning and design process for the freight pipeline terminals so as to be a reference for future UFT system designs regardless of location, size, and depth. Typical UFT system components include the transferable loads, tunnel system, vehicles (capsules or gondolas), gear system, propulsion system, terminal design and intermodal load transfer systems.

This study covers the UFT operational attributes necessary for running the UFT terminals. Corresponding equations are developed to estimate the required headways, number of vehicles, and loading/ unloading handlers/ forklifts as a function of the container flow per day and working hours. According to the operational attributes and load circulation in terminal, schematic designs for the UFT intermodal terminal are created. These typical designs include dimensions in terminal area, location of main lines, bypass lines, layover and maintenance lines, loading/unloading platforms, handlers/forklifts, container stack yards, and intermodal service roads.

UFT SYSTEM COMPONENTS

Route

For the purpose of this research two routes are considered, a short-haul route and a long-haul route. The short-haul route connects the Port of Houston to a proposed intermodal satellite terminal out of Houston and is 15 miles long. The long-haul route connects Port of Houston to a proposed intermodal inland port in Dallas and is 250 mile long. In both intermodal terminals, trucks can access the terminal to load or unload shipping containers.

Load

Two different loads are considered for the study of the UFT system, standard shipping containers and standard US pallet. A shipping container is 40 ft. long, 8 ft. wide, and 9.5 ft. high, and can accommodate 20 US pallets. Shipping containers can have a maximum gross weight of 68,000 lbs. US pallets are 4 ft. long, 3.3 ft. wide, and 3.3 ft. high, and can have up to 4,600 lbs. gross weight. The shipping container size UFT system is most suitable for transportation of cargo from and to sea ports. The Pallet size load is considered for transferring loads in urban areas, from cargo terminals to warehouses or vice versa

Vehicle

Vehicles for transportation of freight can be considered as covered capsules or flatbed gondolas. Capsules are typically metallic with a hatch door at one end for placement or retrieval of the cargo. Covered capsules are recommended for unboxed loads like pallets to prevent load spillage. Covered capsules are not recommended for the shipping containers as there is little chance of load spillage in closed shipping containers.

Tunnel

The tunnel is the underground space required for the transportation of freight. Tunnel in cross section can be cylindrical like a pipeline or rectangular like a culvert. UFT tunnels may be single-track or dual-track. In routes with a high freight demand, dual-track tunnels may be used for transporting freight in both directions. Single-track tunnels are suitable for short haul distances and may be used in each direction based on a temporal schedule. Figures 1 and 2 respectively represent the schematic design for the standard US pallet and standard shipping container UFT systems

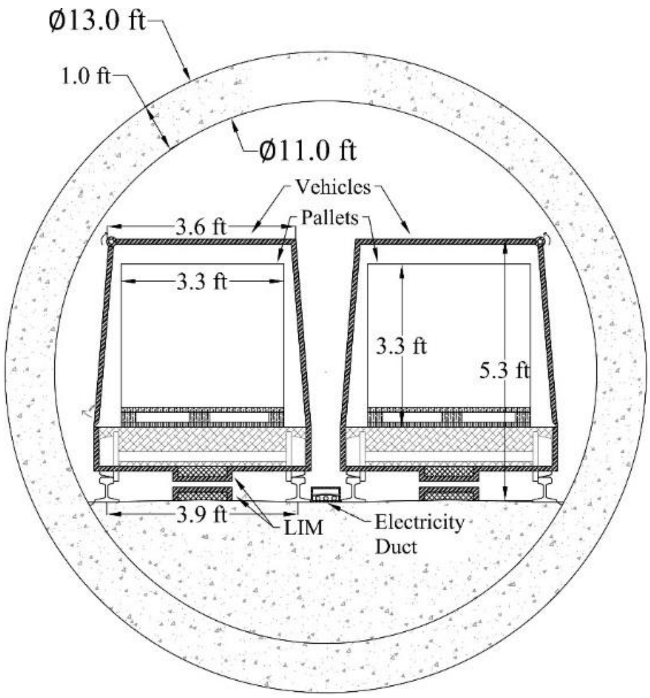

Figure 1. Schematic Design of Pallet-Size Dual-Track Freight Pipeline

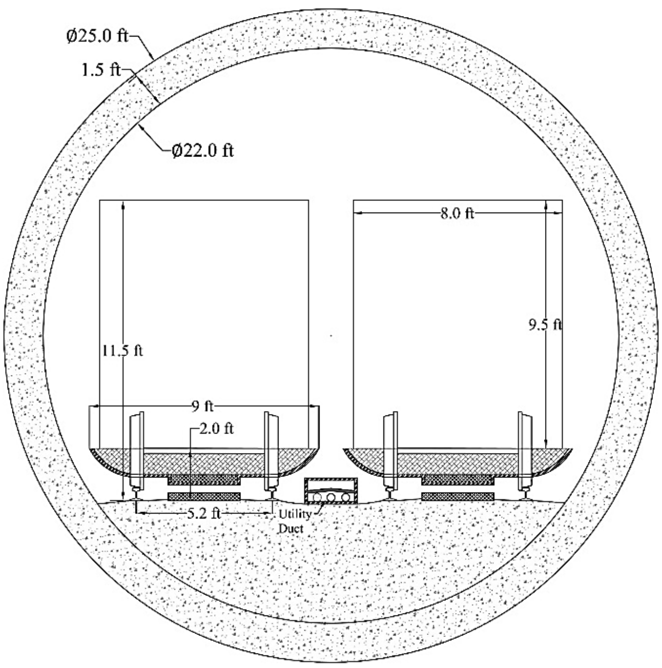

Figure 2. Schematic Design of Container-Size Dual-Track Freight Pipeline

Gear System

Existing freight pipelines use either rubber or steel wheels. Although rubber tires are used in a few freight pipeline systems, it is recommended to use steel wheels in UFT systems as they are less polluting and require less maintenance. Comparing the functional and economic aspects of the running gear systems, the steel wheel and rail with LIM propulsion is identified as the most suitable gear system for the proposed UFT system.

Propulsion System

Linear electric motor is a general term for a non-adhesive propulsion system which generate linear movement through induction or magnetic thrust. Utilization of LIM (Linear Induction Motor) in underground freight transportation systems is advantageous both economically and operationally. First, the narrow height of a LIM system reduces the vehicle height and subsequently the tunnel diameter. This in turn reduces the construction costs (Kaye, 2004). Also, the light weight of LIM decreases the weight of vehicles, which results in lower energy consumption.

Handler/Forklift

Handlers and forklifts are one of the most essential and costly components of a UFT terminal. Special machines are needed in terminal area for loading/unloading of UFT vehicles and trucks. Container handlers are suggested to be used in terminal area. These handles are fast and have a high level of manoeuvrability. Handlers can stack containers up to six levels and have a small turning radius (2017). These handlers should be able to carry containers with 35 ton weight. Pallet forklifts should carry lighter weights up to five tons. In pallet UFT system, electric forklifts which have less environmental pollution may be used.

(a) Shipping Container Handler (b) Pallet Forklift

Figure 3 shows samples of handlers and forklifts for the terminal area.

TERMINAL OPERATION

Capacity and Headway

The operating headway for the UFT system is primarily influenced by the system flow, the number of containers to be delivered in a day and the working hours per day at the origin and destination. The operational headway can be calculated using the following equation:

$$h_{opr} = 3600\frac{T}{Q}$$

where:

hopr= operating headway (secs),

T= working hours (hrs/day), and

Q = System flow (vehicles/day).

Figure 4 shows the operating headway based on the vehicle flow in the system based on 24 hours a day operation.

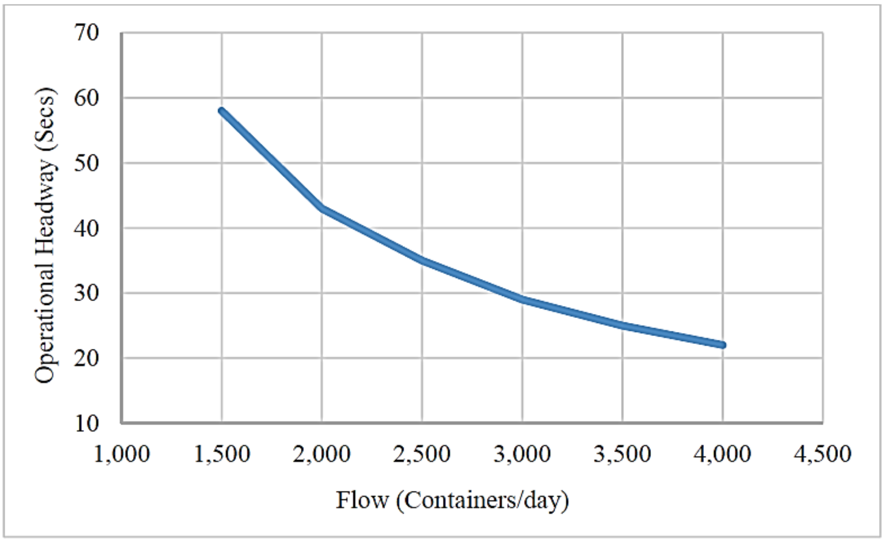

Figure 4. The Relation Between Flow Rates and Operational Headways

Vehicles in Use

In the operation of the UFT system, it is necessary to know the number of vehicles in use when the system is operating. When the UFT system is handling flows lower than capacity, then not all vehicles will be in use. The excess vehicles can be either on stand-by in each terminal's layover section or continue to circulate in the line with no payload. The required number of vehicles depends on the system length, speed, and operational headway, as follows:

$$N_v = 7200\left(\frac{L}{v.h_{opr}}\right) + 1.47\left(\frac{v}{h_{opr}}\right)\left(\frac{1}{a}+\frac{1}{d}\right) \quad \text{(Eq. 2)}$$

where:

Nv = number of vehicles in use,

hopr = operating headway (secs),

L = total length of the route (miles),

v = running speed (mph),

a = acceleration rate (ft/sec^2), and

d = deceleration rate (ft/sec^2).

Equation 2 yields the required number of vehicles in the UFT system in both directions based on operational headways. Table 1 shows how the number of vehicles required in the UFT system varies with operating headway. Table 2 provides the required number of vehicles in two short-haul (15 miles) and long-haul routes (250 miles). For calculation purposes, acceleration and deceleration rates are assumed to be 10 ft/sec^2 and the speed is assumed to be 45 mph.

Table 1. The Relation Between Headway and Number of Vehicles

Route	Long-haul	Short-haul
Length (mile)	**250**	**15**
h_{opr} (seconds)	Number of vehicles	Number of vehicles
15	2,668	161
20	2,001	121
25	1,601	97
30	1,334	80
35	1,143	69

Loading/Unloading Platforms

Terminals should have multiple loading/unloading platforms. In these platforms handlers or forklifts unload full UFT vehicles and load empty UFT vehicles. The time required for handlers to load or unload a shipping container also determines the number of platforms in each loading/unloading section of the terminal. For the proper function of terminal and balance of loading/unloading process, the number of loading and unloading should be equal. Equation 3 shows the relation between flow, UFT system working hours per day, the loading/unloading time, and the number of loading and unloading pair platforms:

$$N_p = \frac{Qt}{3600T} \quad \text{(Eq. 3)}$$

where:

Np = number of loading/unloading pair platforms,

t = loading/unloading time (sec),

T = working hours (hrs/day), and

Q = system flow (vehicles/day).

This number is equal to the number of platforms needed in each loading and unloading section of the terminal. For example, if the loading/unloading process of a UFT vehicle takes 60 seconds and the UFT system has a capacity of 4000 vehicles per day, three pairs of loading /unloading platforms are needed.

Handlers and Forklifts

Handlers are used for both loading and unloading the shipping containers as well as for stacking the shipping containers in the stacking yard and for loading/unloading trucks. Forklifts are used for lifting loads in pallet size UFT systems. The operational characteristics of handlers/forklifts significantly influence the UFT system capacity. A UFT system with a higher capacity requires a higher number of handlers to accommodate arriving or departing freight.

For each loading/unloading platform a total of 4 handler/forklifts are needed in the UFT terminal, two for loading and unloading the UFT vehicles to the stacking yard and two for loading and unloading trucks from the stacking yard. If we denote Nt to be the total number of handlers required in the system, then Nt = 4NP. A number of additional (backup) handlers will also be needed in case of emergency or breakdown of the operating handlers. It is reasonable to consider two additional handlers for each section of the terminal (loading and unloading sides) as backups. As a result, the total number of handlers required in the UFT terminal can be calculated as follows: $N_t = 4 \times (N_p + 1)$ (Eq. 4)

where:

Np = number of loading and unloading paired platforms and

Nt = total number of handlers/forklifts required.

For example, in a terminal with three loading/unloading platforms, a total of 16 handlers is required. Table 2 shows the number of loading/unloading platforms and handlers/forklifts required in the UFT terminal in relation to the capacity of the UFT system.

Table 2. The Relation Between Flow Rates (Q) and Number of Forklifts/Handlers (Nt)

Q (Containers/day)	Number of platform pairs (N_p)	Number of Handlers/Forklifts (N_t)
1,500	1	8
2,000	2	12
2,500	2	12
3,000	3	16
3,500	3	16
4,000	3	16
4,500	4	10

TERMINAL DESIGN

The scope of this section is to develop a schematic design for the UFT system terminals. The terminal design specifications include rail facility design and layout, freight handling, highway access, planning and environmental considerations, and project timescales (2016). The development of individual freight terminals demands a detailed approach for freight flows, handling processes, equipment selection, the role of information communication technologies (ICTs) in freight transport, and the operational and control rules. Therefore, the design and operational analysis of these processes are significant components in providing a state-of-the-art functional design (2016).

As mentioned, the first step in this part would be line facility design and layout. A schematic terminal design plan has been developed which includes main lines, underpass lines, bypass shunts, loading/unloading platforms, truck service roads, handler locations, land-side transfer areas, and container stacking yards. A key component of the UFT terminal is the loading and unloading platforms. A total of three loading/unloading platform pairs are sufficient for UFT system with capacity of 4000 vehicles per day. If a higher capacity UFT system is needed, the number of platforms could be increased to handle additional container flows.

Figure 5 shows a schematic layout of a typical UFT terminal for standard shipping containers. As vehicles arrive, they are directed to the first available unloading platform. Bypass shunts are designed to alleviate queueing of arriving vehicles during the peak time. Unloading the freight on each platform by using a handler is estimated to take about 60 seconds. In turn, the minimum headway between consecutive vehicles could be as low as 20 seconds. Therefore, there is a potential for a traffic back-up without bypass shunts to allow vehicles to continue downstream of the track to the next available platform.

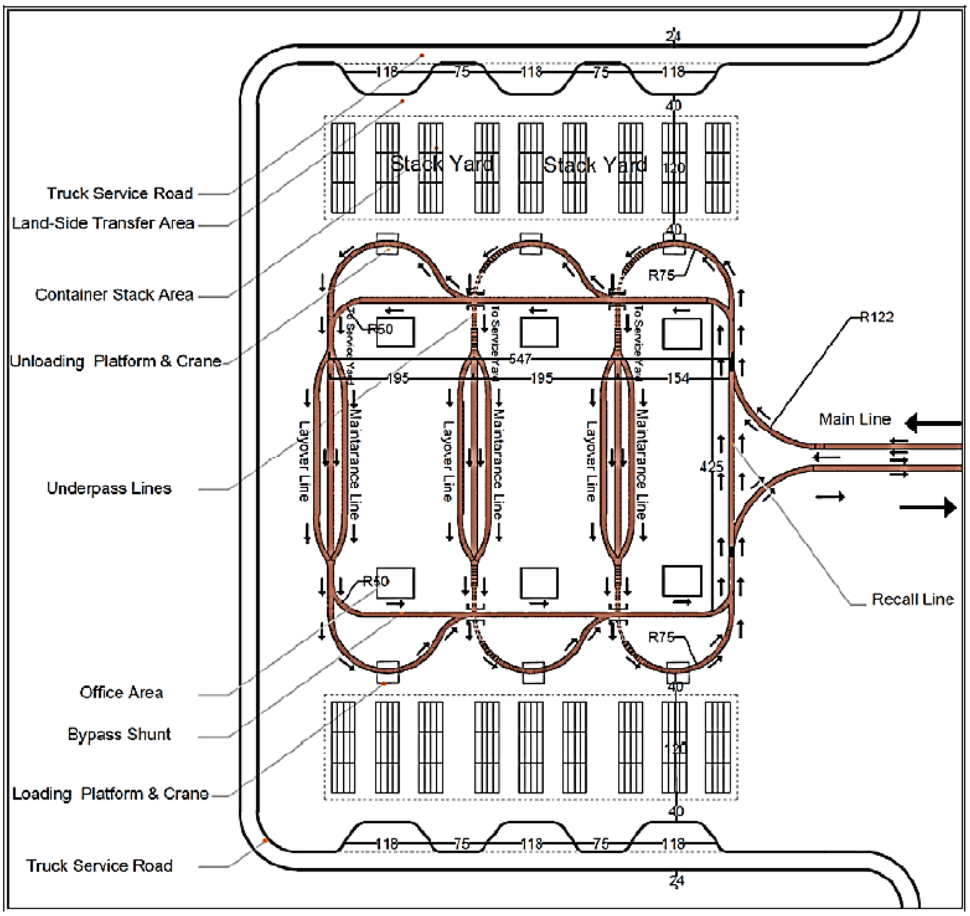

Figure 5. Schematic Design of UFT terminal for Shipping Container Loads.

After unloading their freight, vehicles are directed beyond the loading platform through the underpass lines. Underpass lines pass beneath the bypass shunts and are designed with an approximate 10% grade. They direct the vehicles to the loading platforms or, if need be, to the layover and maintenance lines for service or repairs. Layover lines and maintenance lines run parallel to the main line to allow vehicles to return to the main line when needed. Vehicles then pass underneath a second bypass shunt and proceed to the outgoing loading platform to be loaded with outbound freight and be directed to the outgoing main lines. Although this typical terminal design is for shipping container size loads, the same concept can be used for pallet size loads in a smaller scale. Figure 6 is a three-dimensional model of a UFT terminal and circulation of cargo and trucks in the terminal.

Figure 6. Three-Dimensional Model of UFT Terminal and Cargo/Truck Circulation.

CONCLUSION

In this paper a schematic design for the intermodal terminal of a UFT system is presented and the necessary parameters for its operation are calculated. UFT system is a new mode of freight transportation that needs design standards and operational specifications. This paper has aimed at developing operational attributes and presenting a typical design for the intermodal terminal of a UFT system. The proposed terminal design can be used for different UFT systems and its overall plot and operational configuration can be tailored for either long-haul or short-haul systems. Regardless of the size and length of the UFT system, developed equations in this paper establish the relation between vehicles headway, UFT system capacity, and number of vehicles circulating in the system. In addition, the relation between headway, number of loading/unloading platforms and number forklifts/handlers in the terminal are calculated.

The design of the terminal is based on the required number of loading/unloading platforms. For each platform, bypass shunts and underpass lanes are proposed and designed.

Since the headway is smaller than the loading/unloading time, multiple platforms are required. The unloaded freight can be kept in stacking yard and empty vehicles can stop in layover lines. The terminal is circumferenced by a highway and trucks have direct access to the stacking yard. On one side of terminal trucks unload their freight and on the other side, they pick up their loads. For each loading/unloading platform, at least four forklifts/handlers are needed.

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